Vestibular Assessment in the Pediatric Population

Running title

Pediatric vestibular examination

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INTRODUCTION

Vestibular disorders in children are not as uncommon as generally assumed. Prevalence rates vary from 0.7 to 15%[1], although certain groups (e.g. with congenital TORCH-infections, prematurity and/or hearing loss) are known to be at higher risk for vestibular dysfunctions[2-6]. Moreover, recent studies suggest that the impact of vestibular dysfunctions may be greater than previously thought and may not be limited to delayed (gross) motor development[7], but also be accompanied with learning difficulties[8] (e.g. reading, writing) or cognitive deficits[9] (e.g. visuospatial orientation, attention). In young children (<6yr), both history taking and vestibular assessment are challenging: children report vague symptoms lacking the appropriate vocabulary to describe their complaints[10], vestibular tests are not very child-friendly and the available equipment is not adapted to the pediatric population[11]. The aim of this paper is to propose simple adjustments to create a child-friendly version of the standard vestibular assessment which provides objective information on the function of the different parts of the vestibular system.

METHODS

Subjects

Fifty-eight healthy subjects (35 girls, 23 boys) between 5 months and 6 years of age were divided into six age categories, each containing eight children. As greater variation was expected amongst the youngest subjects (5mo-1yr), 18 subjects were recruited for this group.

The study was approved by the Ghent University Hospital's Ethics Committee. Informed consents were obtained from the children's parents.

Test protocol

In our hospital, patients at risk for vestibular dysfunctions (with hearing loss, congenital cytomegalovirus infection, cochlear implant and/or vestibular symptoms) are subjected to an extensive vestibular test protocol as summarized in Table 1. This examination is preceded by thorough history taking guided by questionnaires and accompanied with ocular motor testing to identify central vestibular disorders, and motor assessment to determine the impact on the motor development[7]. This extensive assessment should provide good insight in the vestibular function and allow appropriate referral to other specialists (e.g. neurologist, physiotherapist), if needed.

Children between 5 months and 3 years of age are examined with the video Head Impulse Test (vHIT), rotatory test and cervical Vestibular Evoked Myogenic Potential (cVEMP) test. These three tests allow a quick and child-friendly evaluation of both the canal and otolith system. Moreover, the results are not affected by possible middle ear pathologies, which are frequently present in young children. From the age of three, the test battery is extended with four caloric irrigations and the ocular Vestibular Evoked Myogenic Potential (oVEMP) test, since prolonged alertness and cooperation are more feasible in this older age category.

The sequence of examinations (Table 1) in younger children (<3yr) is mainly tied to the required level of alertness and cooperation, as these are particularly limited in this group and have a substantial effect on test-reliability. In older children (>3yr), tests are ranked by increasing invasiveness.

Adjustments for children

vHIT (semicircular canal)

The Synapsys (Marseilles, France) vHIT Ulmer device is ideal for application in children as no calibration is needed prior to registration and it does not require wearing goggles. One examiner, placed behind the registering stand-alone camera, attracts the child's attention to an appealing visual stimulus (toy). The other examiner, placed behind the child, performs the head maneuvers (Fig. 1a). Consequently, one can always rely on the subjective evaluation by the examiner behind the camera in case objective measurement fails. In our clinic, vHIT standardly entails lateral canal testing. Adding vertical canal testing is dependent on clinical indications (e.g. history taking, imaging results) and the child's cooperation as it is more challenging and time-consuming than lateral canal testing. Normative data for children have recently been published by Wiener-Vacher and Wiener[12].

Rotatory test (lateral semicircular canal)

The child is seated in a car seat on the rotatory chair, the head fixed by a neck pillow and headband (Fig. 1b). An examiner walks along with the chair, keeping the child comforted but aroused and aware of the presence of an adult (especially important with hearing-impaired children). Alertness is stimulated by music playing through a speaker attached to the rotatory chair. Electronystagmography (ENG) is preferred over videonystagmography to register eye movements, since ENG-measurements are not interrupted by closing the eyes and it does not require wearing goggles, which are generally not well-tolerated and not well-fitted for children. The latter would result in incomplete darkening and the possibility of fixation during testing.

cVEMP (saccule)

To bypass possible middle ear disorders, the cVEMP-test is performed with bone conduction (59 dB nHL/129 dB SPL). Subjects are tested in supine position, the upper body placed upon a

sloping pillow and the head turned and supported by only the examiner's hand (Fig. 1c). The child is stimulated to turn the head by placing the parent at the side of the non-test ear, provided with toys.

Caloric test (lateral semicircular canal)

In order to increase the feasibility of the caloric test, we reduced the deviation from body temperature from 7°C to 5°C. In our experience, these temperatures (32°C and 42°C) are better tolerated than the standard temperatures (30°C and 44°C), increasing the chances of tolerating four irrigations and obtaining the complete caloric response diagram. Cold irrigations are performed first, so that at least one irrigation in each ear can be completed in case the child shows increasing resistance during warm irrigations. Water is preferred as stimulus because it induces better responses, although air insufflation can be a valuable alternative in very young children (<3yr) as tympanostomy tubes are common in this group and air insufflation may be perceived as less invasive than water.

oVEMP (utricle)

An air conduction stimulus (95 dB nHL/119 dB SPL) is used since the maximal intensity of a standard bone conductor is insufficient and a mini-shaker is not well-tolerated by young children. A bone conductor combined with a special amplifier reaching higher intensity levels could be a valuable alternative. An upward gaze of 30° is elicited using a smartphone attached to the wall, playing a video clip.

RESULTS

Table 2 gives an overview of the success rates of the vestibular tests across the different age categories. Causes of failure or unreliability of the test results are summarized in Table 3. The duration of the vestibular test protocol was approximately 1 hour for the abridged protocol in younger (<3yr) children and 2 hours for the extensive protocol (>3yr).

DISCUSSION

In literature, as well as in clinical practice, insufficient attention has been given to vestibular assessment in the pediatric population. Centers that do perform vestibular examinations in young children often confine themselves to a limited test protocol (e.g. only cVEMP) or less accurate evaluation techniques (e.g. subjective measurements instead of quantitative interpretation of the response parameters).

The results of this paper show that vestibular assessment with an extensive test protocol using objective measures is feasible in young children when some adjustments are made. As summarized in Table 2, the assessment of children between the ages of 2 and 3 years seems to be the most challenging, as their cooperation can be limited and they may be alarmed by the unfamiliarity of the test situation. It should be noted that the subjects in this study were healthy voluntarily-participating children. In patients with vestibular complaints, parents could show more dedication to persevere with the examinations, as they hope to find some answers in the test results. Concerning the test protocol in children younger than three, the rotatory test appears to be the most difficult to conduct reliably. When the extensive protocol for older children is considered, the caloric test remains the most challenging, reaching higher success rates as the child grows older. Consistent with the consensus in literature, the highest success rates for the VEMPs demonstrate that these are the most feasible vestibular tests in the pediatric population[13]. The relatively new vHIT is also promising as it is fast, child-friendly, easy to

conduct, and it provides ear-specific information about the semicircular canal system. Despite its non-invasive character, success rates of vHIT are still lower compared to VEMPs. This is because the vHIT requires more cooperation (fixating the target, enduring holding the head) and registration is impossible in case of crying or persistent eye blinking. The latter is the main cause of failure in older subjects (>3yr) as was the case in our study in one 4-year-old child. Note that vHIT-testing is applicable for typically developing infants from the age of 5 to 6 months, as active head control is required to obtain a safe and reliable measurement.

Objective and extensive vestibular examination is indispensable to enable detailed and accurate evaluation of vestibular function. Comparison of the patient's results with normative data of a healthy control group makes more clear-cut conclusions and early identification of (even partial) vestibular dysfunctions possible. Apart from these inter-subject comparisons, objective measurements also allow more meaningful interpretations of intra-subject comparisons (i.e. follow-up assessments). Therefore, vestibular examination should be more established in the pediatric population for patients with an increased risk for vestibular deficits[2-6] (e.g. with congenital TORCH-infections, prematurity and/or hearing loss) and/or vestibular complaints[14]. This should ensure early identification and referral for vestibular rehabilitation in order to facilitate the child's early development[15,16].

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REFERENCES

1. Gioacchini FM, Alicandri-Ciufelli M, Kaleci S, Magliulo G, Re M. Prevalence and diagnosis of vestibular disorders in children: a review. Int J Pediatr Otorhinolaryngol. 2014;78(5):718-724.
2. Maes L, De Kegel A, Van Waelvelde H, Dhooge I. Rotatory and collic vestibular evoked myogenic potential testing in normal-hearing and hearing-impaired children. Ear Hear. 2014;35(2):e21-32.
3. Zagolski O. Vestibular tests in infants with TORCH and after CNS infections. Przegl Lek. 2005;62(8):769-771.
4. Ecevit A, Anuk-Ince D, Erbek S, et al. Comparison of cervical vestibular evoked myogenic potentials between late preterm and term infants. Turk J Pediatr. 2012;54(5):509-514.
5. Cushing SL, Gordon KA, Rutka JA, James AL, Papsin BC. Vestibular end-organ dysfunction in children with sensorineural hearing loss and cochlear implants: an expanded cohort and etiologic assessment. Otol Neurotol. 2013;34(3):422-428.
6. Maes L, De Kegel A, Van Waelvelde H, et al. Comparison of the Motor Performance and Vestibular Function in Infants with a Congenital Cytomegalovirus Infection or a Connexin 26 Mutation: A Preliminary Study. Ear Hear. 2017;38(1):e49-e56.
7. De Kegel A, Maes L, Baetens T, Dhooge I, Van Waelvelde H. The influence of a vestibular dysfunction on the motor development of hearing-impaired children. Laryngoscope. 2012;122(12):2837-2843.
8. Braswell J, Rine RM. Evidence that vestibular hypofunction affects reading acuity in children. Int J Pediatr Otorhinolaryngol. 2006;70(11):1957-1965.
9. Popp P, Wulff M, Finke K, Ruhl M, Brandt T, Dieterich M. Cognitive deficits in patients with a chronic vestibular failure. J Neurol. 2017;264(3):554-563.

10. Miyahara M, Hirayama M, Yuta A, Takeuchi K, Inoki T. Too young to talk of vertigo? Lancet. 2009;373(9662):516.
11. Valente LM. Assessment techniques for vestibular evaluation in pediatric patients. Otolaryngol Clin North Am. 2011;44(2):273-290, vii.
12. Wiener-Vacher SR, Wiener SI. Video Head Impulse Tests with a Remote Camera System: Normative Values of Semicircular Canal Vestibulo-Ocular Reflex Gain in Infants and Children. Front Neurol. 2017;8:434.
13. Zhou G, Dargie J, Dornan B, Whittemore K. Clinical uses of cervical vestibular-evoked myogenic potential testing in pediatric patients. Medicine (Baltimore). 2014;93(4):e37.
14. Wiener-Vacher SR. Vestibular disorders in children. Int J Audiol. 2008;47(9):578-583.
15. Rine RM, Braswell J, Fisher D, Joyce K, Kalar K, Shaffer M. Improvement of motor development and postural control following intervention in children with sensorineural hearing loss and vestibular impairment. Int J Pediatr Otorhinolaryngol. 2004;68(9):1141-1148.
16. Braswell J, Rine RM. Preliminary evidence of improved gaze stability following exercise in two children with vestibular hypofunction. Int J Pediatr Otorhinolaryngol. 2006;70(11):1967-1973.

FIGURES

Fig. 1. Test setup of the minimal pediatric test protocol for children younger than three. a) Video Head Impulse Test in a seven-month-old child. The examiner behind the registering stand-alone camera is attracting the child's attention to an appealing visual stimulus. The examiner placed behind the child is performing the head maneuvers. b) Rotatory test in a five-month-old child. The child is seated in a car seat, with the head fixated by a neck pillow, a headband and additional manual fixation by the examiner walking along, if necessary. c) Cervical Vestibular Evoked Myogenic Potential test in a one-year-old child, placed upon a sloping pillow and the head turned and supported by only the examiner's hand.

TABLES

Table 1. Pediatric vestibular test protocol

5 months – 3 year	3 year – 6 year
1. vHIT	1. vHIT
2. Rotatory Test	2. cVEMP
3. cVEMP	3. oVEMP
	4. Rotatory Test
	5. Caloric Test

vHIT = video Head Impulse Test; cVEMP = cervical Vestibular Evoked Myogenic Potentials; oVEMP = ocular Vestibular Evoked Myogenic Potentials

220 **Table 2.** Representation of the proportion of children across the different age categories in
221 which each test could be successfully and reliably conducted

Age category	Subjects	Median age (mo)	Success rate (%)				
			vHIT†	cVEMP	oVEMP	Rotatory test	Caloric test
5mo-1yr	n=18	7,0	72,2	100,0		88,9	
1yr-2yr	n=8	17,0	100,0‡	100,0		62,5	
2yr-3yr	n=8	29,0	85,7‡	75,0		50,0	
Total group <3yr	**n=34**	**10,5**	**81,3**	**94,1**		**73,5**	
3yr-4yr	n=8	44,0	100,0	100,0	100,0	100,0	62,5
4yr-5yr	n=8	54,5	87,5	100,0	100,0	100,0	85,7§
5yr-6yr	n=8	67,5	100,0	100,0	100,0	100,0	100,0
Total group >3yr	**n=24**	**54,5**	**95,8**	**100,0**	**100,0**	**100,0**	**82,6**

†In this table, only success rates of the lateral vHIT are shown. ‡ Data of 1 vHIT registration in 2 age categories are missing due to a technical issue. § In 1 patient, the data of the caloric test is missing as the test was not performed due to the presence of tympanostomy tubes.

vHIT = video Head Impulse Test; cVEMP = cervical Vestibular Evoked Myogenic Potentials; oVEMP = ocular Vestibular Evoked Myogenic Potentials

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Table 3. Causes of unreliability of the obtained test results or failure of conducting the vestibular tests

	vHIT	cVEMP	oVEMP	Rotatory test	Caloric test
Impossible	- Crying - Constant blinking - Not tolerating holding the head	- Severe protest (pulling of electrodes, not staying in position)	Not applicable	- Severe protest (pulling of electrodes, excessive head movement, failure of calibration)	- Fear
Unreliable	- Insufficient number of accepted vHIT-sequences - Large variation in gain-values - Unacceptable vHIT-traces	- Impossibility of repro-duction of the cVEMP-response (severe protest)	Not applicable	- Head movement - Falling asleep - Insufficient reaction due to severe protest (squeezing the eyes)	- Tolerating only 2 (cold) irrigations

vHIT = video Head Impulse Test; cVEMP = cervical Vestibular Evoked Myogenic Potentials; oVEMP = ocular Vestibular Evoked Myogenic Potentials

SUPPORTING INFORMATION LEGEND

Video 1. Video Head Impulse test in a subject younger than three

Filename: Video_1_SuppInfo.mp4

Video 2. Video Head Impulse test in a subject older than three

Filename: Video_2_SuppInfo.mp4

Video 3. Rotatory test in a subject younger than three. Note that this video was recorded in an illuminated room for demonstration purposes. Evidently, the actual examination is performed in complete darkness.

Filename: Video_3_SuppInfo.mp4

Video 4. Rotatory test in a subject older than three. Note that this video was recorded in an illuminated room for demonstration purposes. Evidently, the actual examination is performed in complete darkness.

Filename: Video_4_SuppInfo.mp4

Video 5. Cervical Vestibular Evoked Myogenic Potential test in a subject younger than three

Filename: Video_5_SuppInfo.mp4

Video 6. Cervical Vestibular Evoked Myogenic Potential test in a subject older than three

Filename: Video_6_SuppInfo.mp4

Video 7. Ocular Vestibular Evoked Myogenic Potential test in a subject older than three

Filename: Video_7_SuppInfo.mp4

Video 8. Caloric test in a subject younger than three. Note that this video was recorded in an illuminated room for demonstration purposes. Evidently, the actual examination is performed in the dark.

Filename: Video_8_SuppInfo.mp4

Video 9. Caloric test in a subject older than three. Note that this video was recorded in an illuminated room for demonstration purposes. Evidently, the actual examination is performed in the dark.

Filename: Video_9_SuppInfo.mp4